

**U.S. Department of Energy  
Cooperative Agreement Number:  
DE FC02-01CH11080**

**Advanced Natural Gas Reciprocating  
Engine Program**

**Peer Review**  
April 23-24, 2002

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Product Manager  
Waukesha Engine, Dresser, Inc.

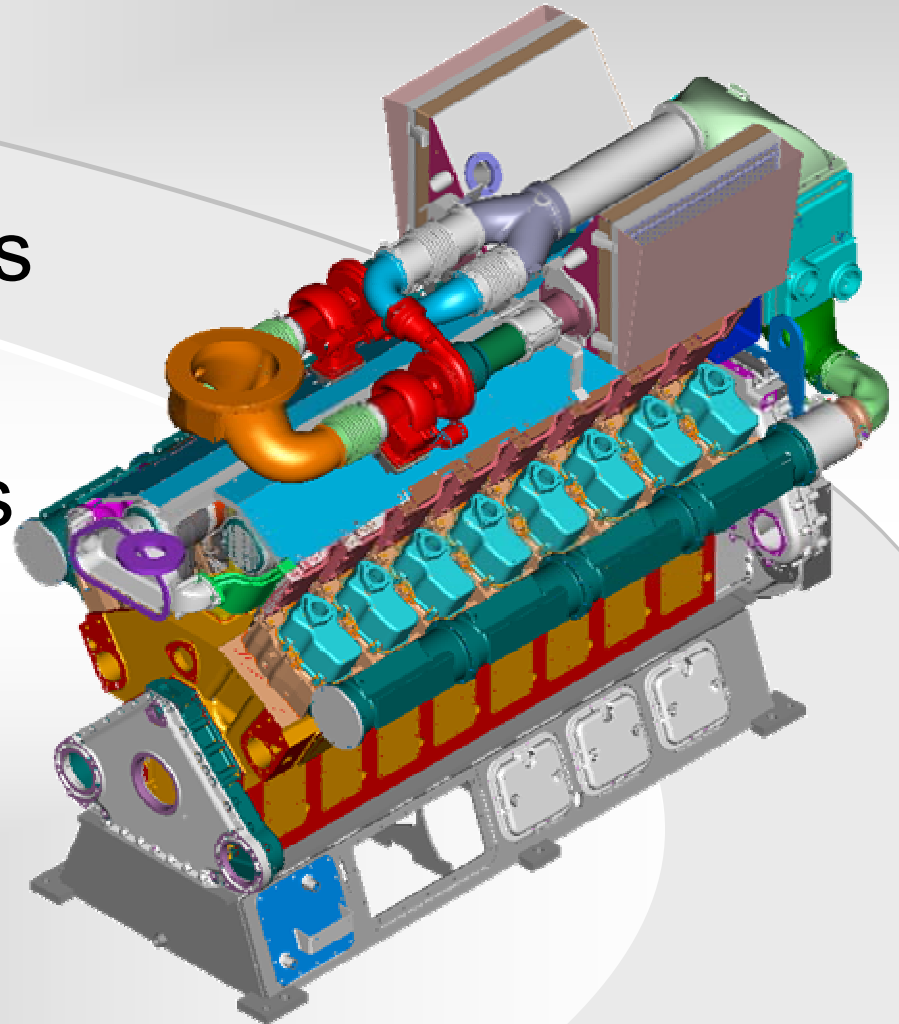


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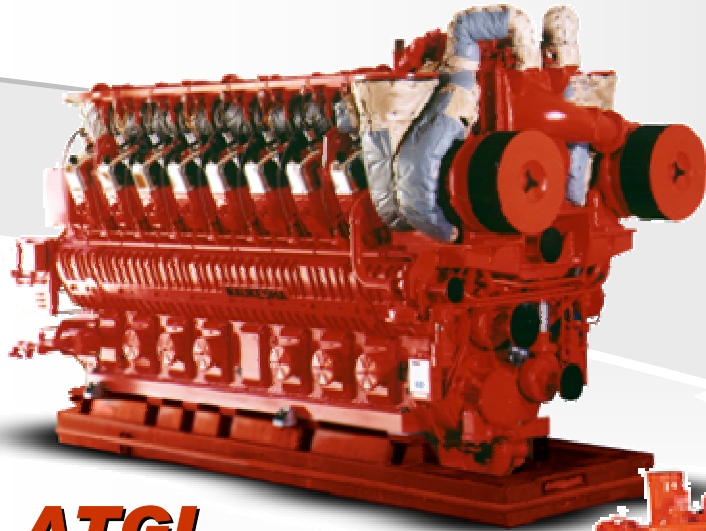
# Peer Review Topics

- Waukesha Engine
- Program Objectives
- R & D Approach
- Technical Progress

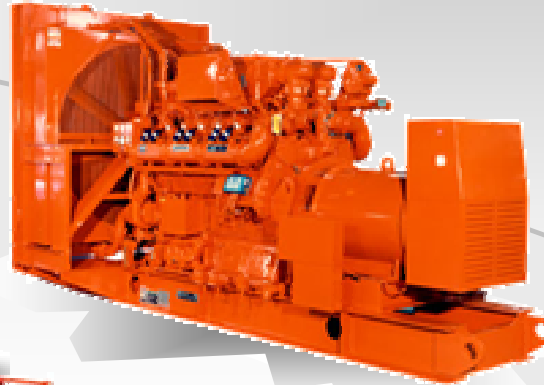


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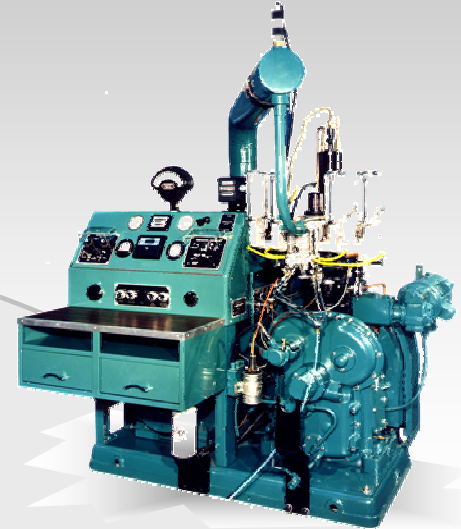
# Waukesha Engine Products



**ATGL**



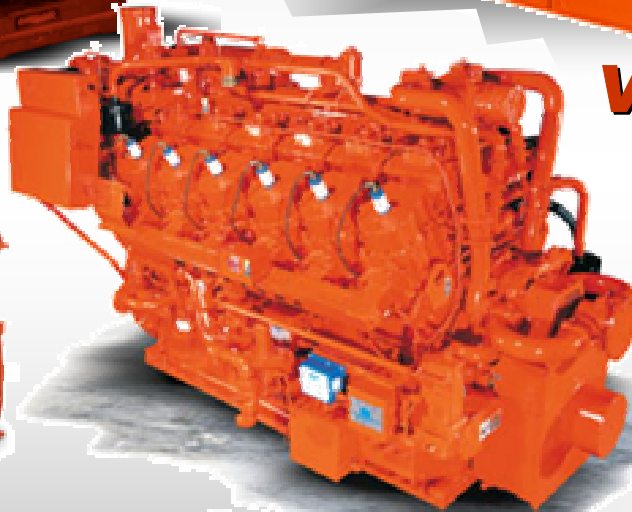
**VGF**



**CFR**



**VSG**



**VHP**



**Waukesha  
Genuine Parts**



Waukesha

# Waukesha Engine Worldwide



## 8 Regional Offices

- Calgary
- Houston
- Denver
- Dubai
- Beijing
- Appingedam
- Singapore
- India

- Manufacturing Facility
- Regional Office
- Facility & Regional Office

# Waukesha Engine Worldwide



# Waukesha Engine Worldwide



# ARES Objectives

Market implementation of high efficiency, low emission, stationary natural gas engines (500 - 6500kW) by 2010.

Description	Current	ARES
Efficiency target	37-40%	50%
NO <sub>x</sub> emissions	1-2 g/bhp-hr (3-6 lbs/MW-hr)	0.1 g/hp-hr (0.31 lbs/MW-hr)
Cost (¢/kW-hr)	5 - 6	10% reduction in \$
Availability	95% uptime	Same
Fuel Flexibility	NG, LPG, Bio	NG, Bio (Future)

All goals are interrelated!



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# ARES Commercial Plan 2001-2010

**Typical Start Dates by Phases:**

Current	35-37% BTE, 2g NOx
Phase I	40% BTE, 1.2g NOx
Phase II	45% BTE, 0.25g NOx
Phase III	50% BTE, 0.1g NOx

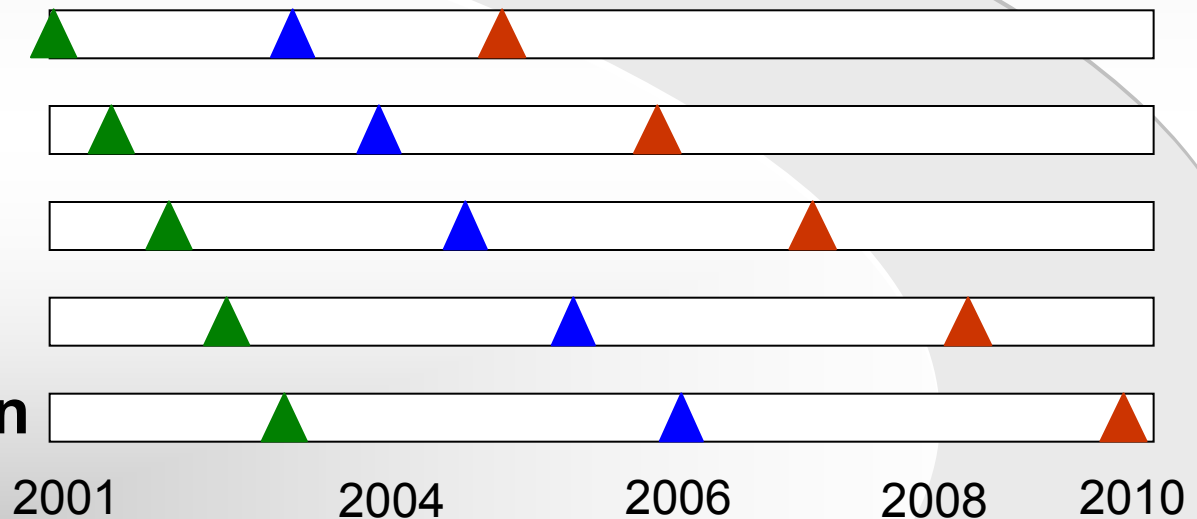
**Concepts**

**Technical Base**

**Platform Base**

**Field Demos**

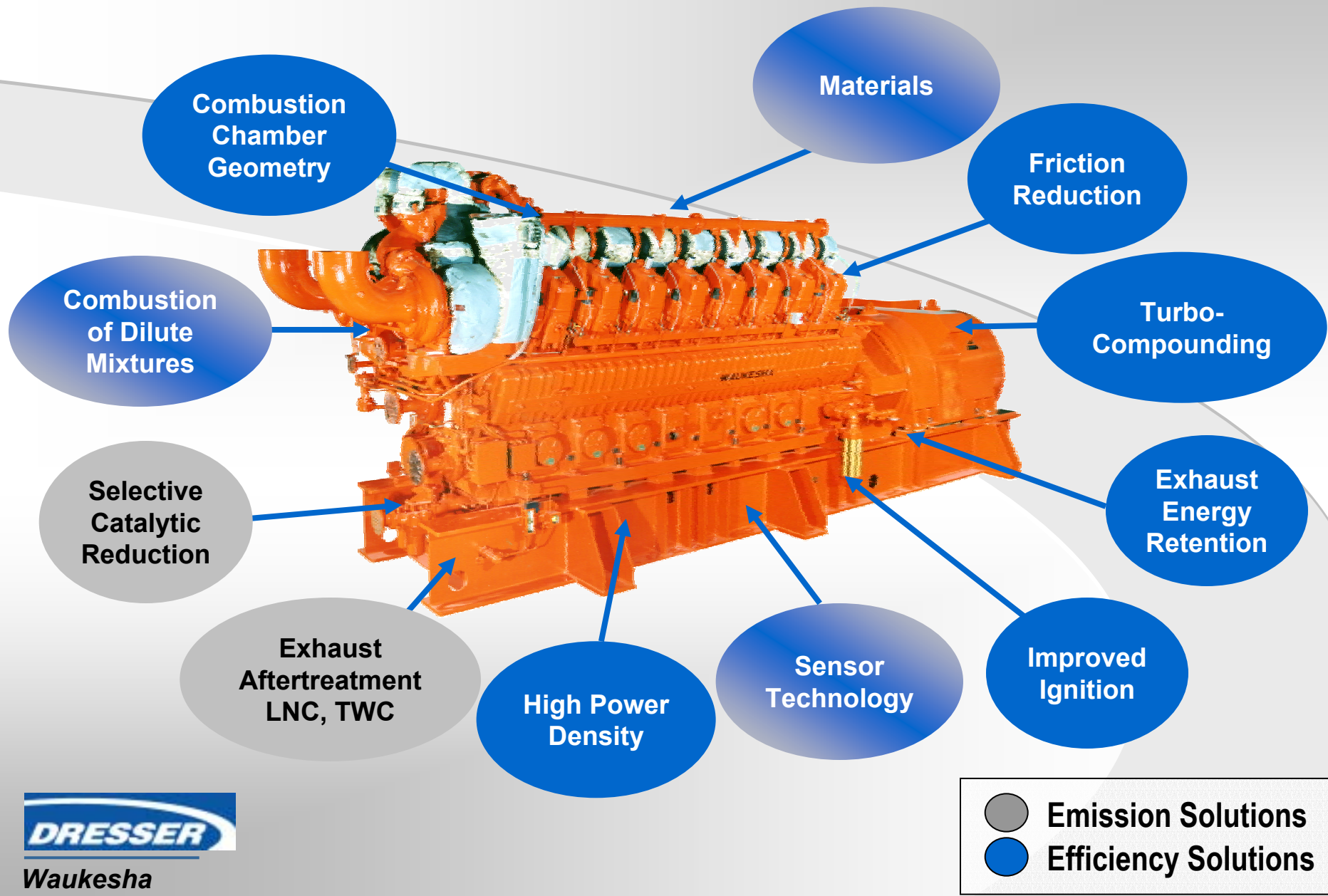
**Commercialization**



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# ARES Solution Paths



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# ARES Technical Path

Technology	Description	Contribution (BTE points)
Miller Cycle	1.5 Expansion Factor	~ 1.7 points
Turbo-Compounding	80% turbine efficiency 95% gear train efficiency	~ 1.5 points
Low Heat Rejection on Exhaust System	60 % heat loss reduction	~ 1.9 points
Low Friction/High BMEP	87% to 91% mechanical efficiency	~ 2.3 points
Burn Rate	20 degree to 18 degree 10 to 90% burn duration	~ 0.7 points
Flow Improvement	20% Improvement	~ 1.2 points
Two-Stage Compression w/Intercooling	80% compressor efficiency per stage, 313 K intercooling	~ 0.4 points





# Waukesha Engine Technical Path

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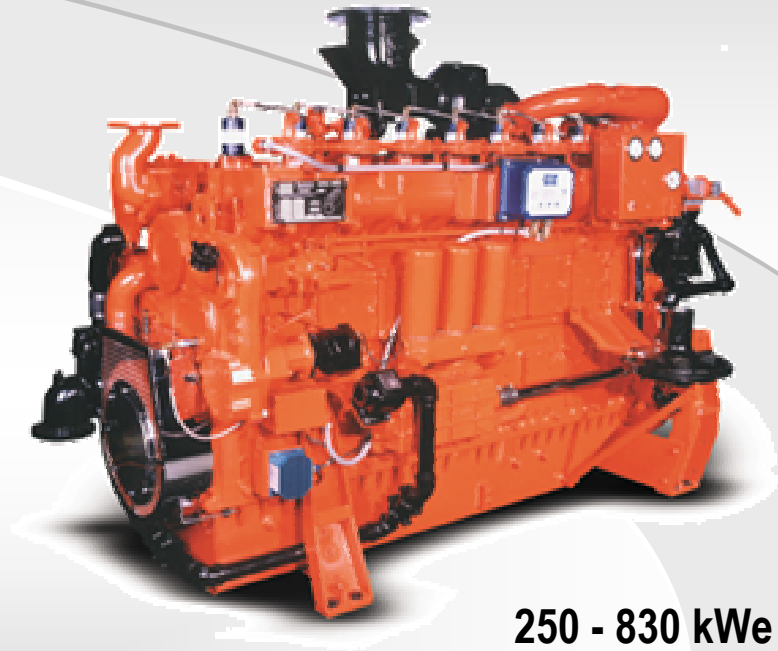


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 Phase I & II  
 Phase II

# Technical Progress: Phase I

- Waukesha VGF Platform
- Maximum Efficiency
  - Stoichiometric 35%
  - Lean Burn 37%
- NOx emissions
  - Lean Burn
    - 1.25 gm/bhp-hr
    - 3.88 lb/mw-hr



250 - 830 kWe



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# Technical Progress: Phase I

VGF Improvement Efficiency	ARES Path	Waukesha Results
Intake System Improvement	1.2 points	0.1
Cyl Head - Air Flow Improvement		0.2
Exhaust Manifold Flow Loss Improvement		0.25
Cyl Head - Heat Transfer	1.9 points	0.4
Exhaust Heat Loss Reduction		0.2
Turbocharger Efficiency Improvements	0.4 points	0.4
Miller Cycle - Conservative	1.7 points	1.05
Miller Cycle - Aggressive		2.4
Total		2.6 to 3.9

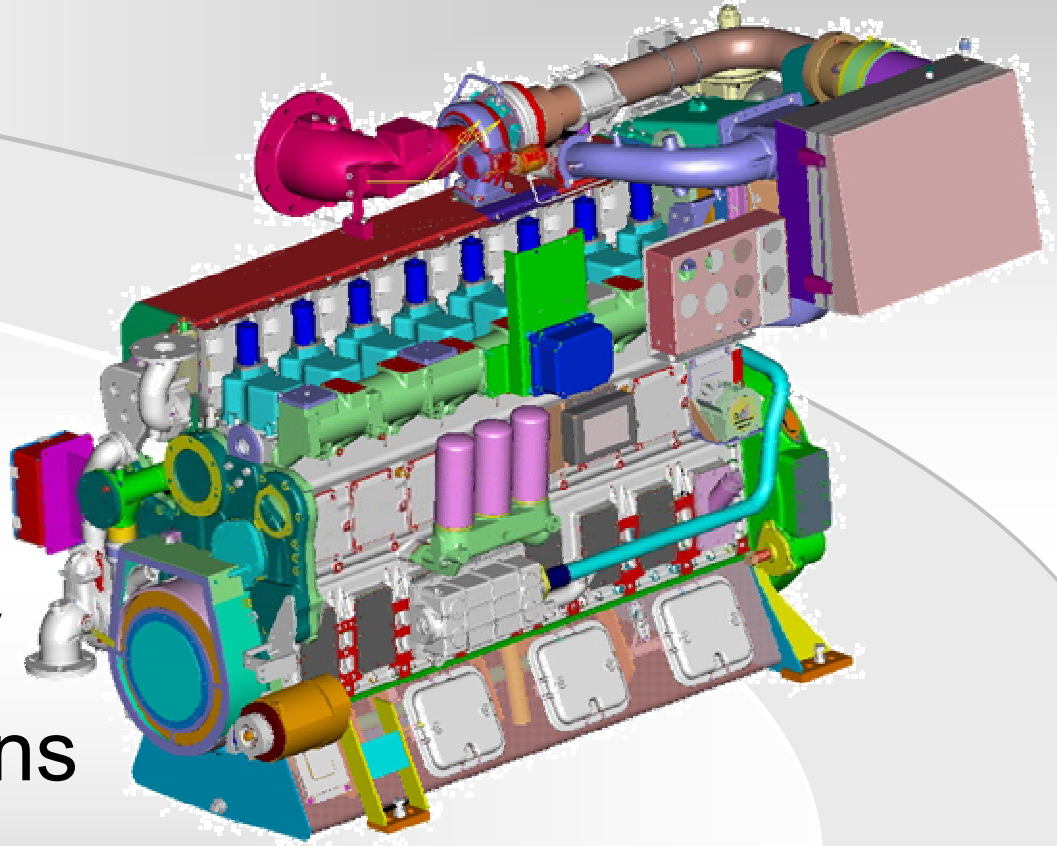


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Potential: VGF Efficiency Gain from 37% to 40.9%

# Technical Progress: Phase I

- Miller Cycle
- Improved Combustion Systems
- 40% Efficiency
- Same Emissions

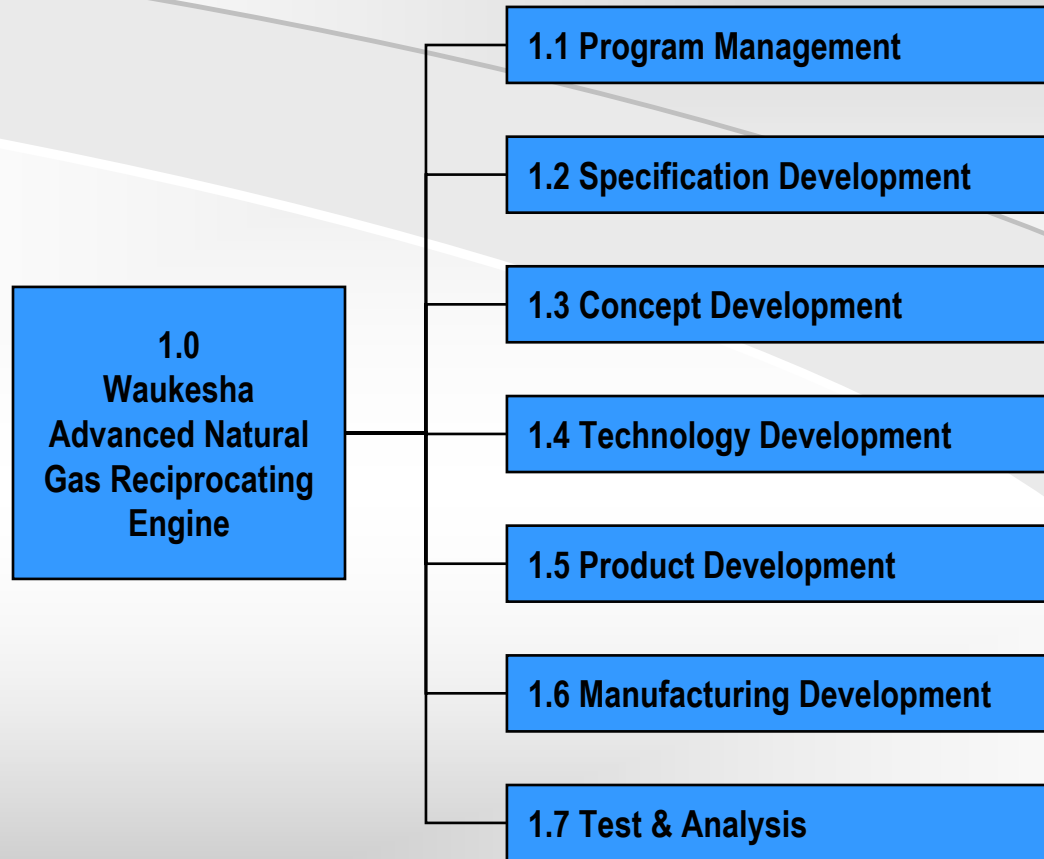


**Conclusion:** ARES Path results in a more efficient product for near term production



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# APG: Phase II Work Breakdown Structure



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# APG Project Partners

## Supplier

Borg-Warner Turbochargers & tech. support

TRW Valves & tech. support

Winsert Valve seats & tech. support

## Customer

NICOR End user & field demonstration

## Consultant/Lab/University

CSU/MIT Friction reduction program

Digital Engines KIVA combustion modeling

MRI Manufacturing consulting

Rexnord Component durability testing

Ricardo Design analysis services

SWRI Concept testing





# APG Project Tasks

**Task 1: Component Development & Testing**

Task 2: System Development & Testing

Task 3: Engine Integration & Preparation

Task 4: Engine Fabrication & Proof Test

Task 5: Pre-Commercial Demonstration



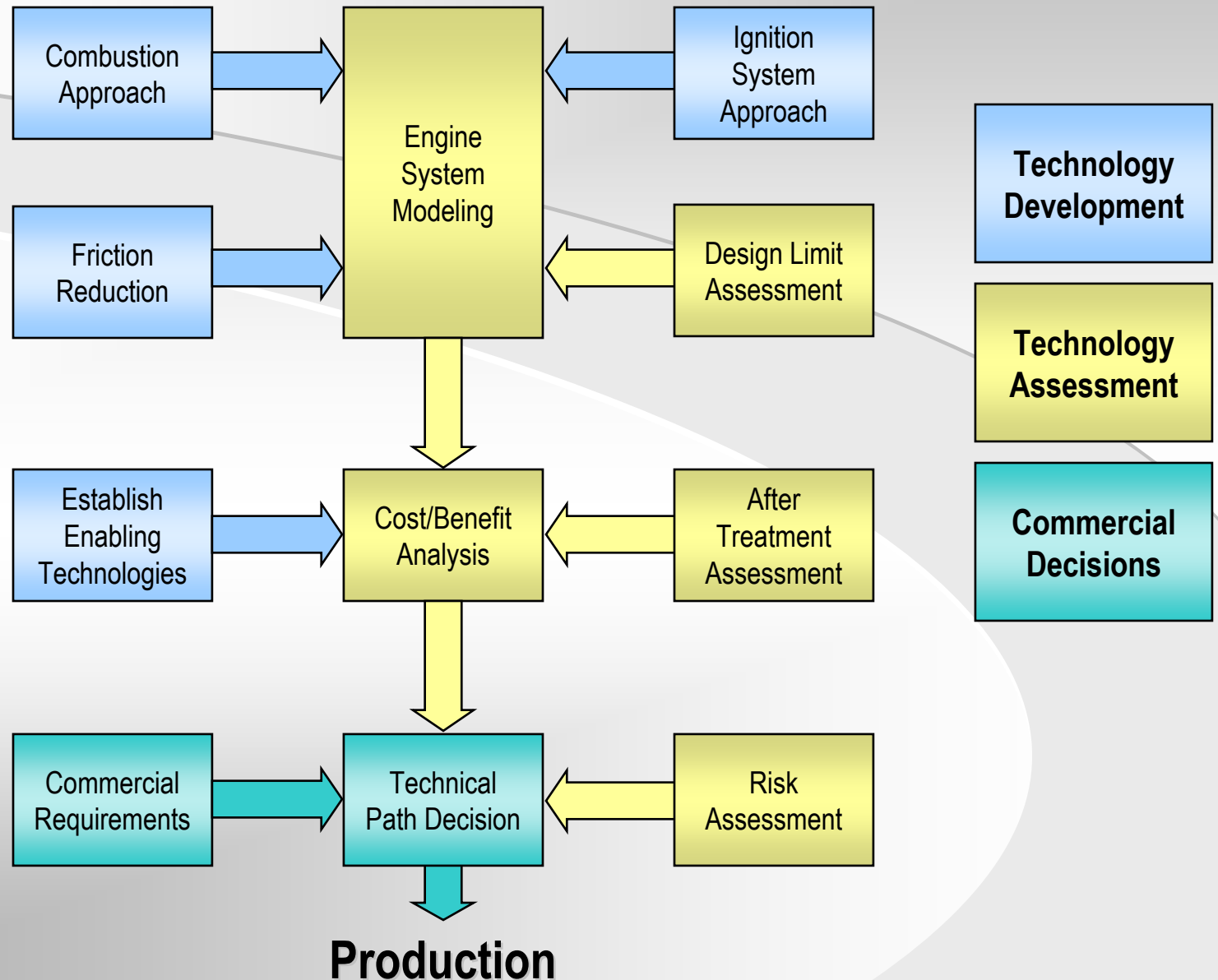
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# APG Technical Barriers/Project Risks

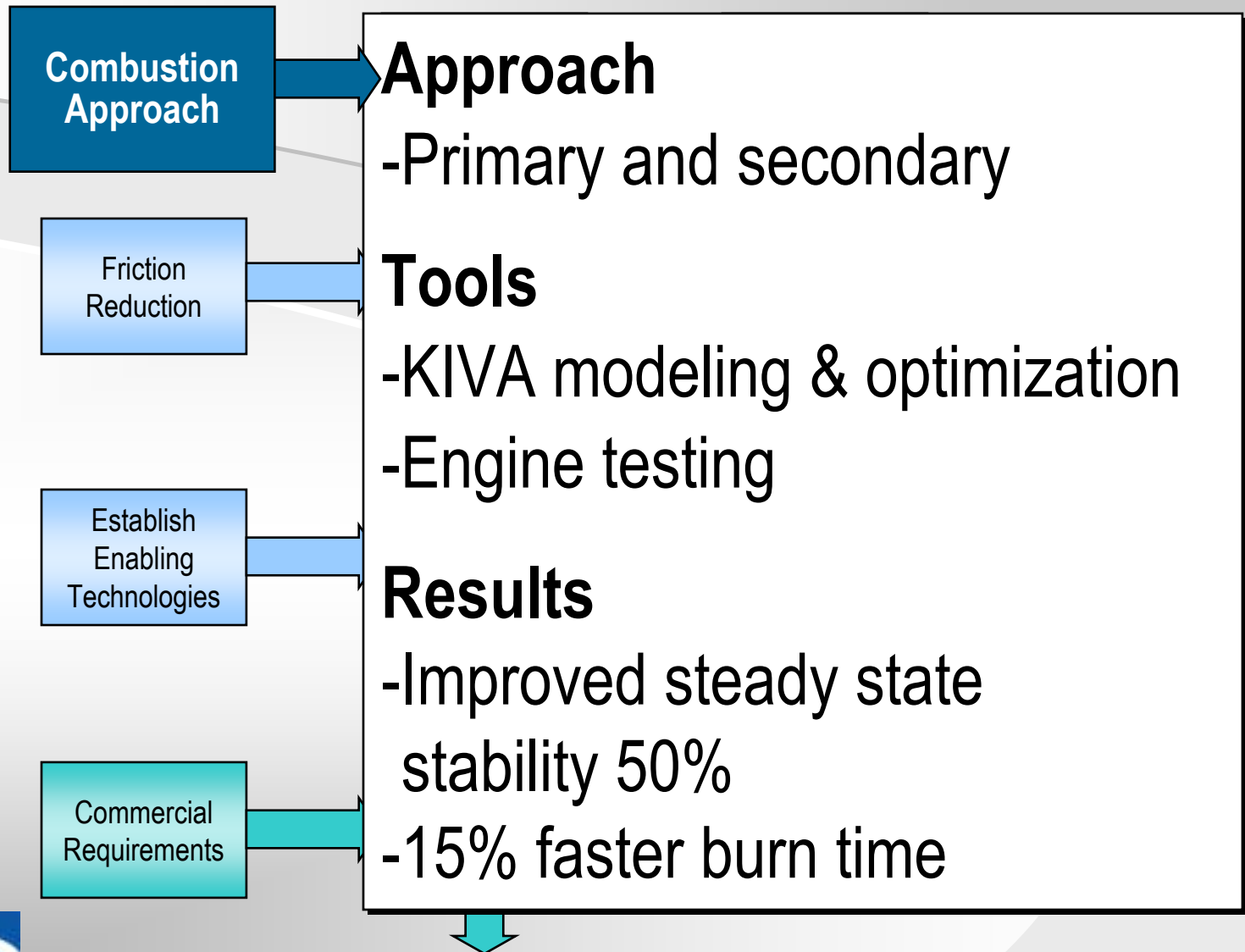
- Combustion stability with high diluent
- Ignition system reliability, durability, and cost
- High cylinder pressure
- Friction reduction
- After treatment efficiency and cost



# APG Technology Path



# APG Progress Update



# APG Progress Update

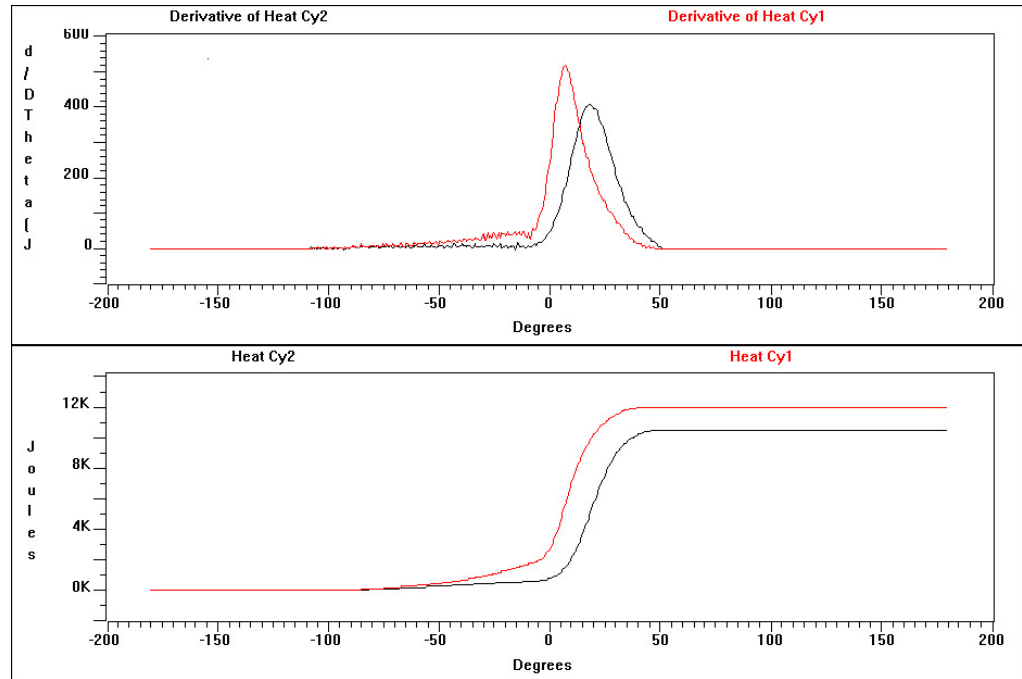
Combustion  
Approach

Friction  
Reduction

Establish  
Enabling  
Technologies

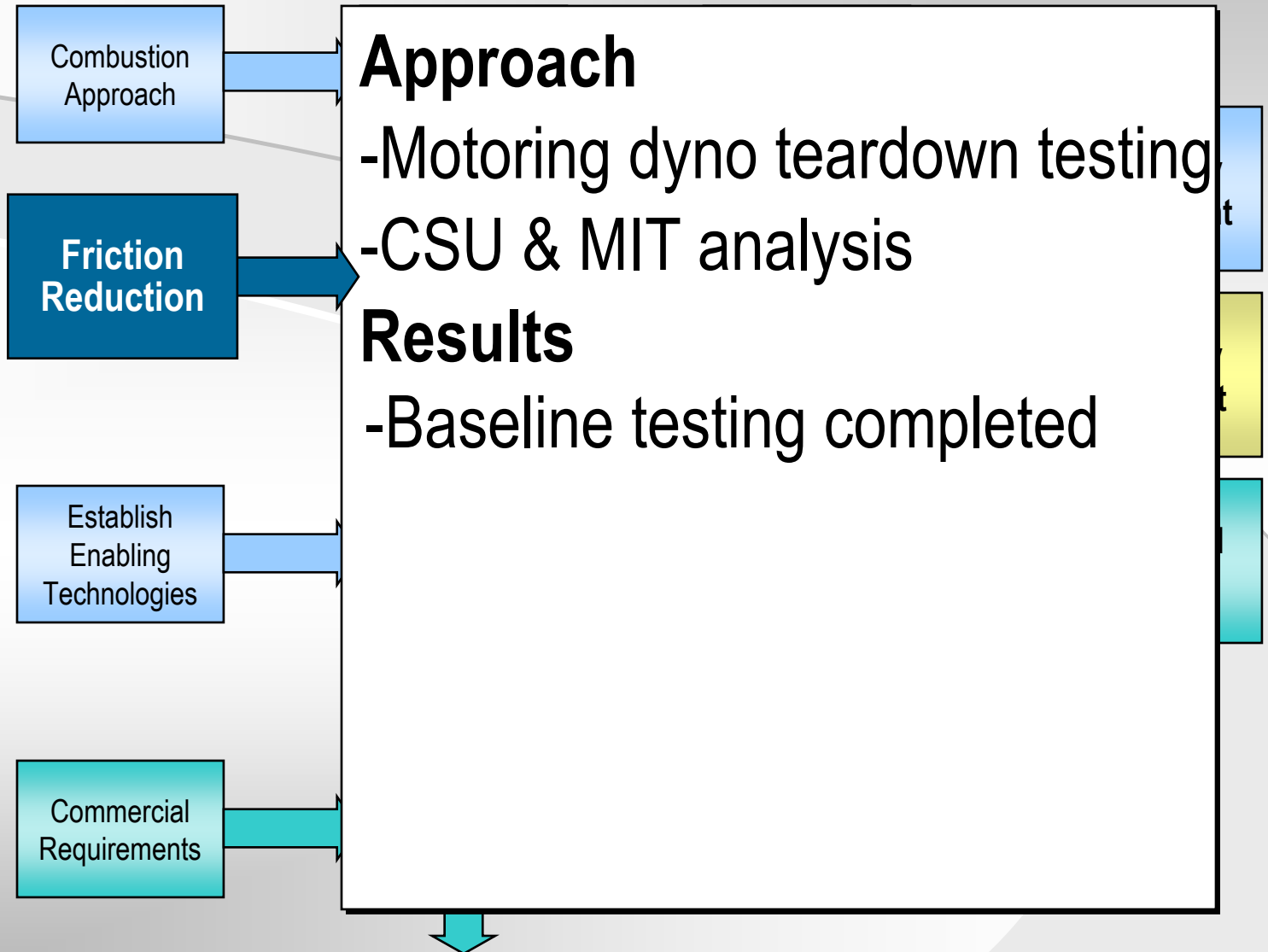
Commercial  
Requirements

## Heat Release



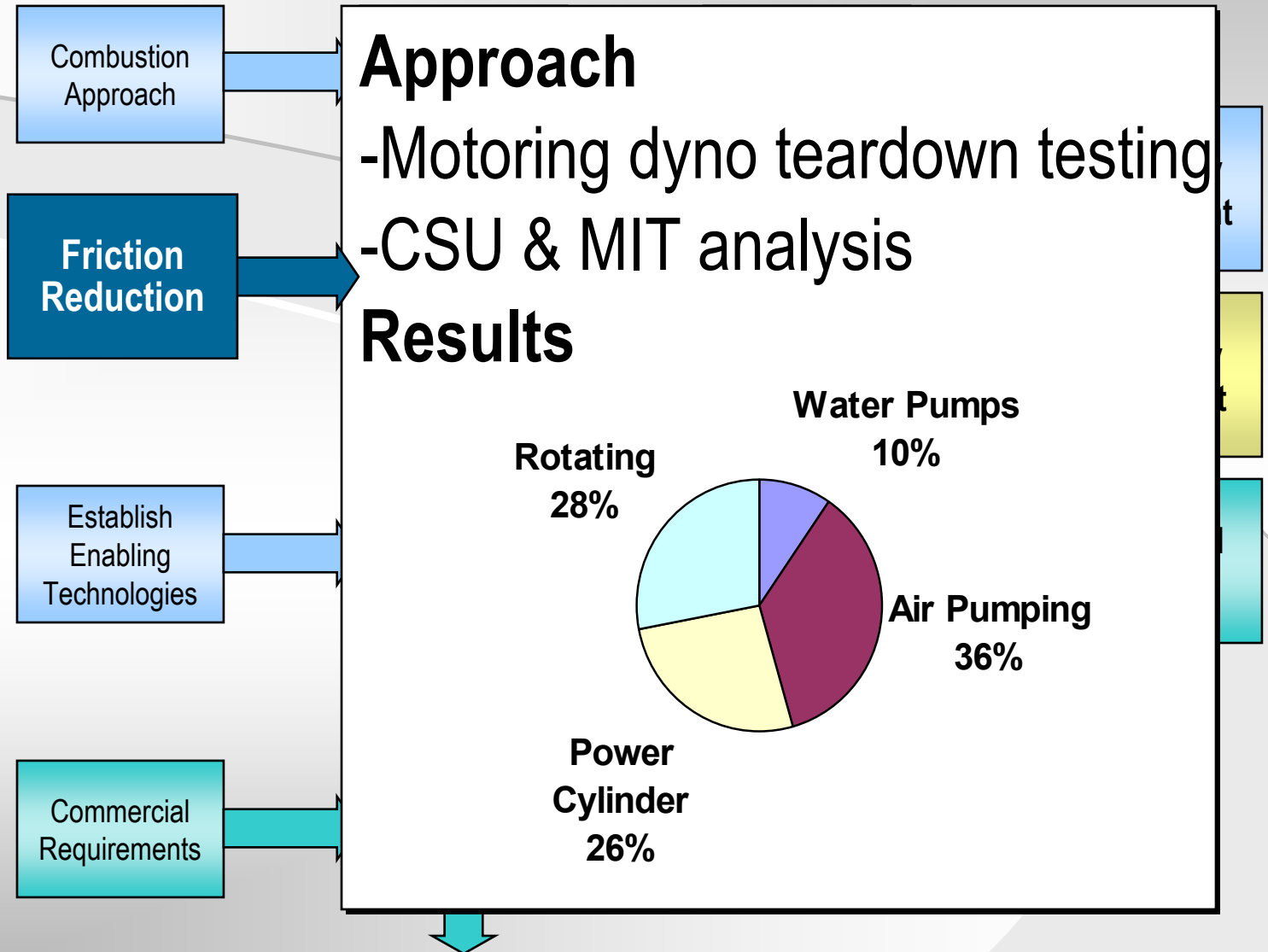
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# APG Progress Update



Waukesha

# APG Progress Update



Waukesha

# APG Progress Update

## Approach

- Four ignition system concepts being investigated
- Engine testing
- Collaborating with CSU on laser ignition

## Results

- Increased spark plug life by 50%

Ignition  
System  
Approach

Design Limit  
Assessment

After  
Treatment  
Assessment

Risk  
Assessment

Technology  
Development

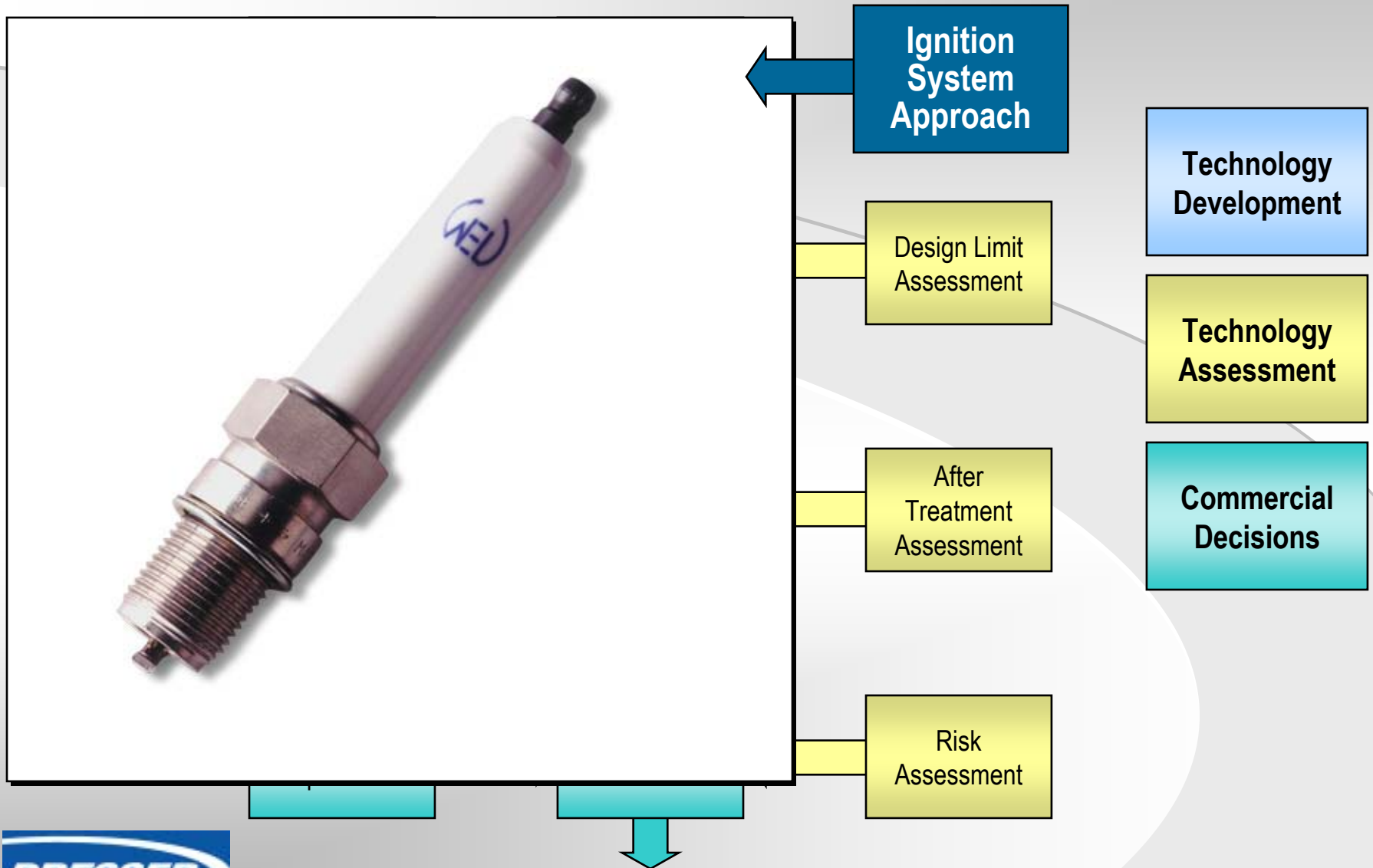
Technology  
Assessment

Commercial  
Decisions





# APG Progress Update



# APG Progress Update

## Approach

- Finite Element Analysis (FEA) directed redesign
- Classical design analysis

## Results

- FEA performed on crankcase, crankshaft, and piston.
- Design limit assessment performed

Ignition  
System  
Approach

Design Limit  
Assessment

After  
Treatment  
Assessment

Risk  
Assessment

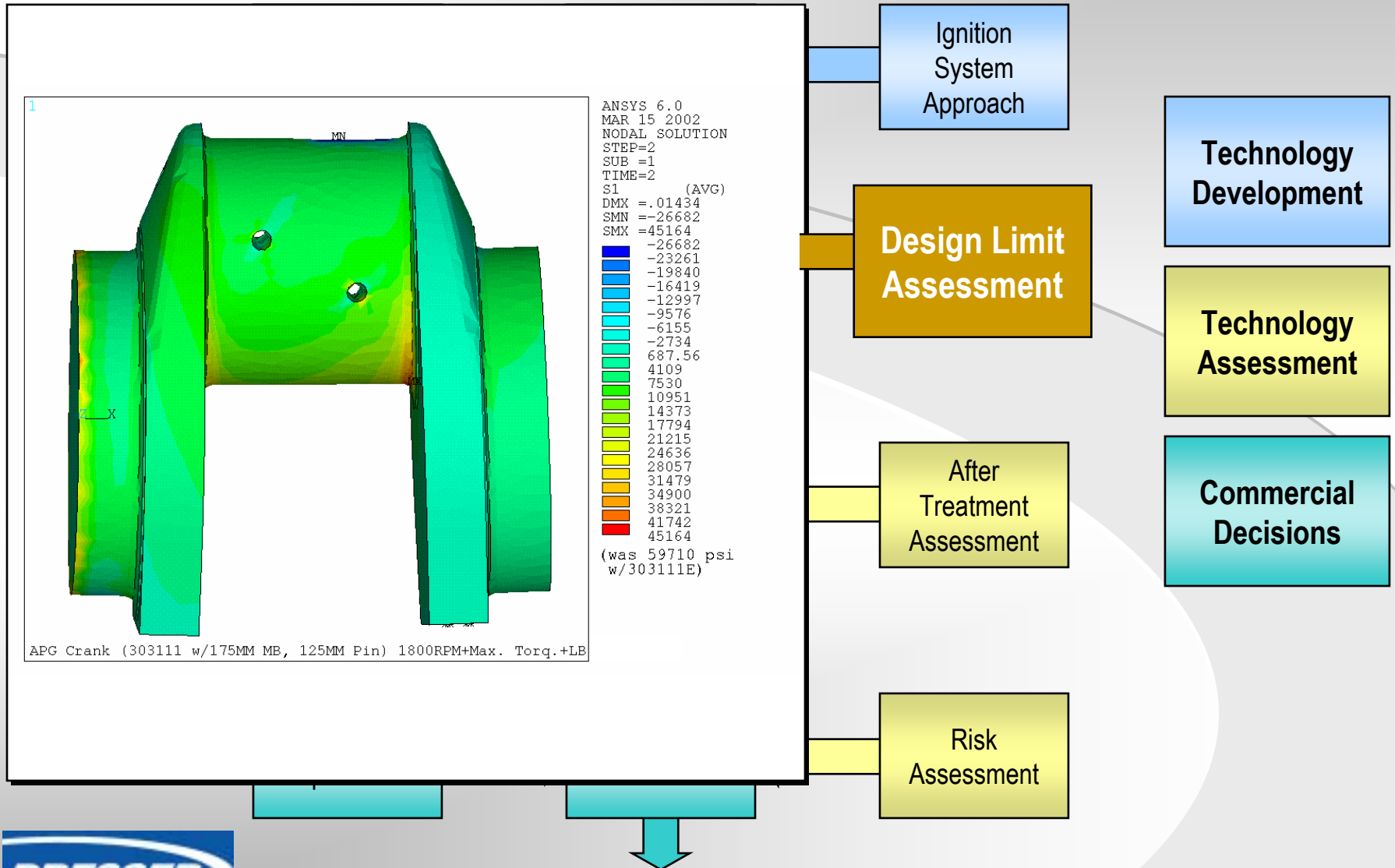
Technology  
Development

Technology  
Assessment

Commercial  
Decisions

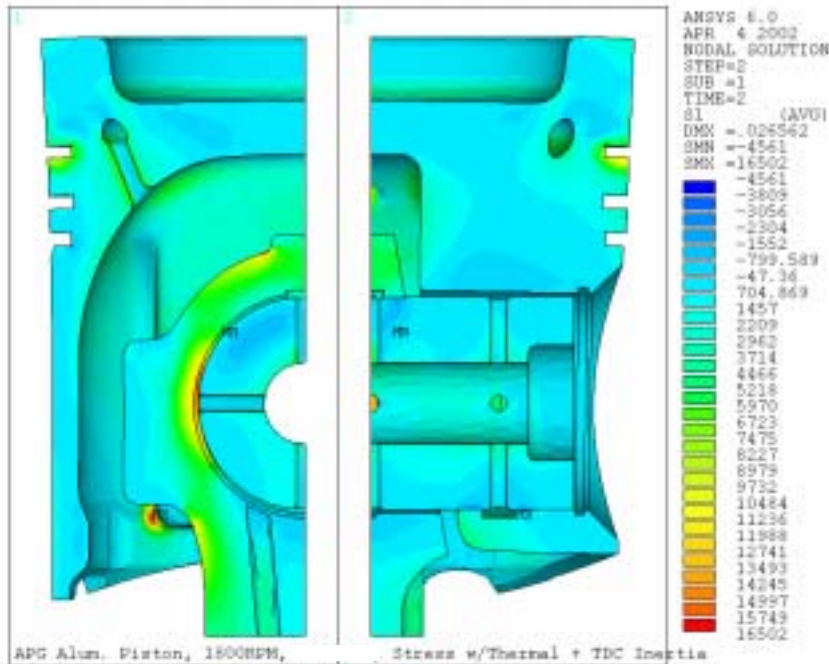


# APG Progress Update



Waukesha

# APG Progress Update



Ignition  
System  
Approach

Design Limit  
Assessment

After  
Treatment  
Assessment

Risk  
Assessment

Technology  
Development

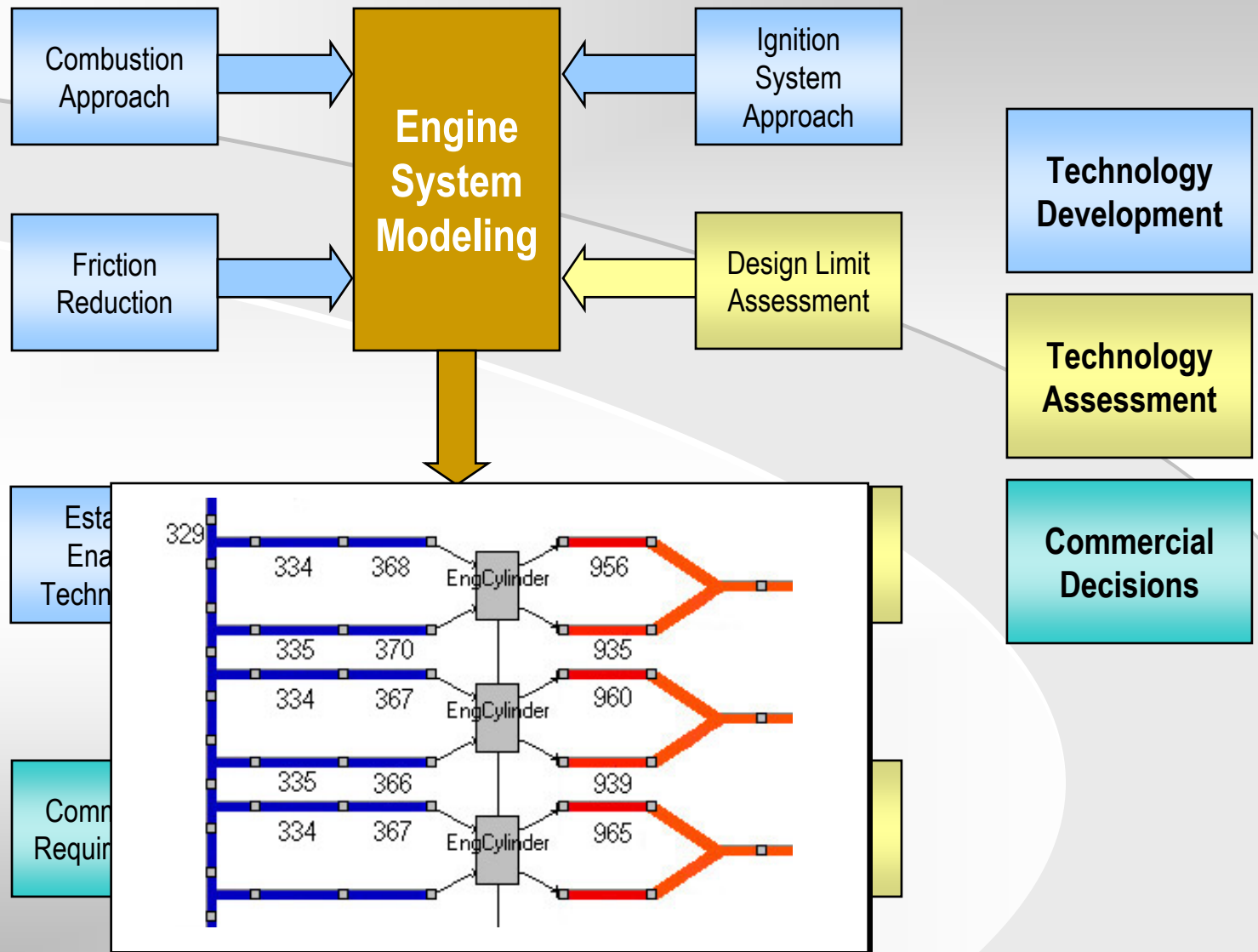
Technology  
Assessment

Commercial  
Decisions



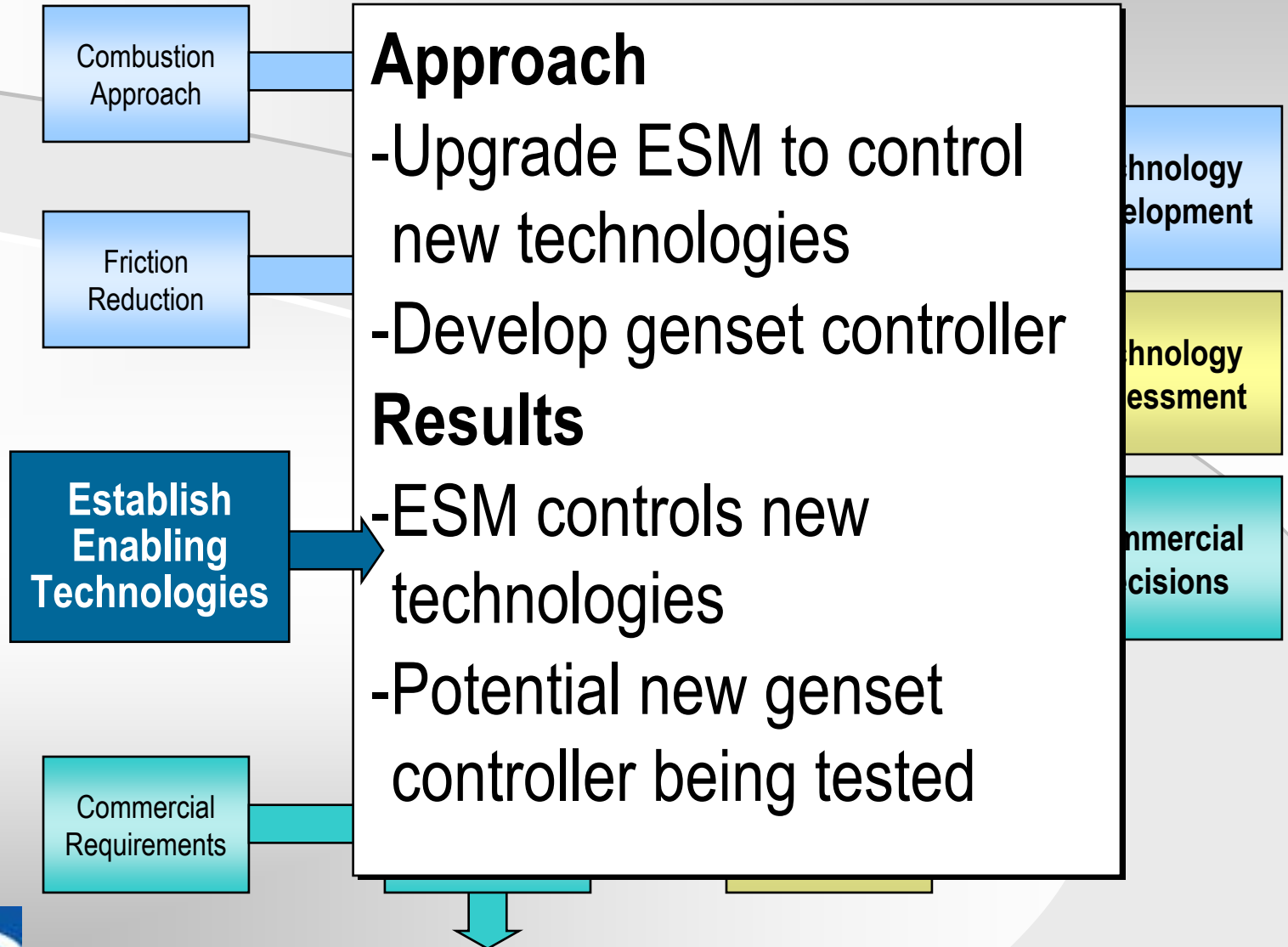
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# APG Progress Update

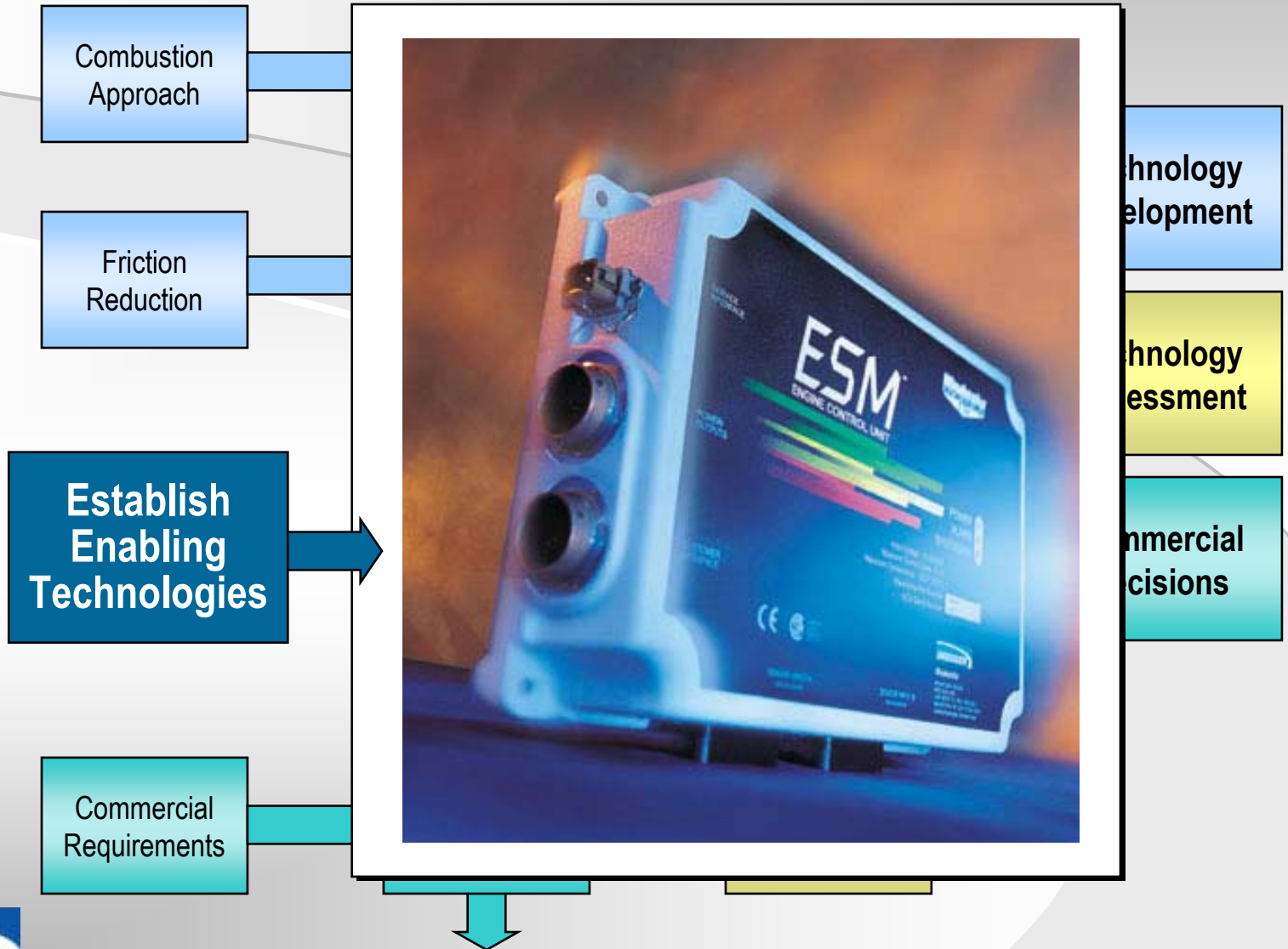


Waukesha

# APG Progress Update



# APG Progress Update



Waukesha

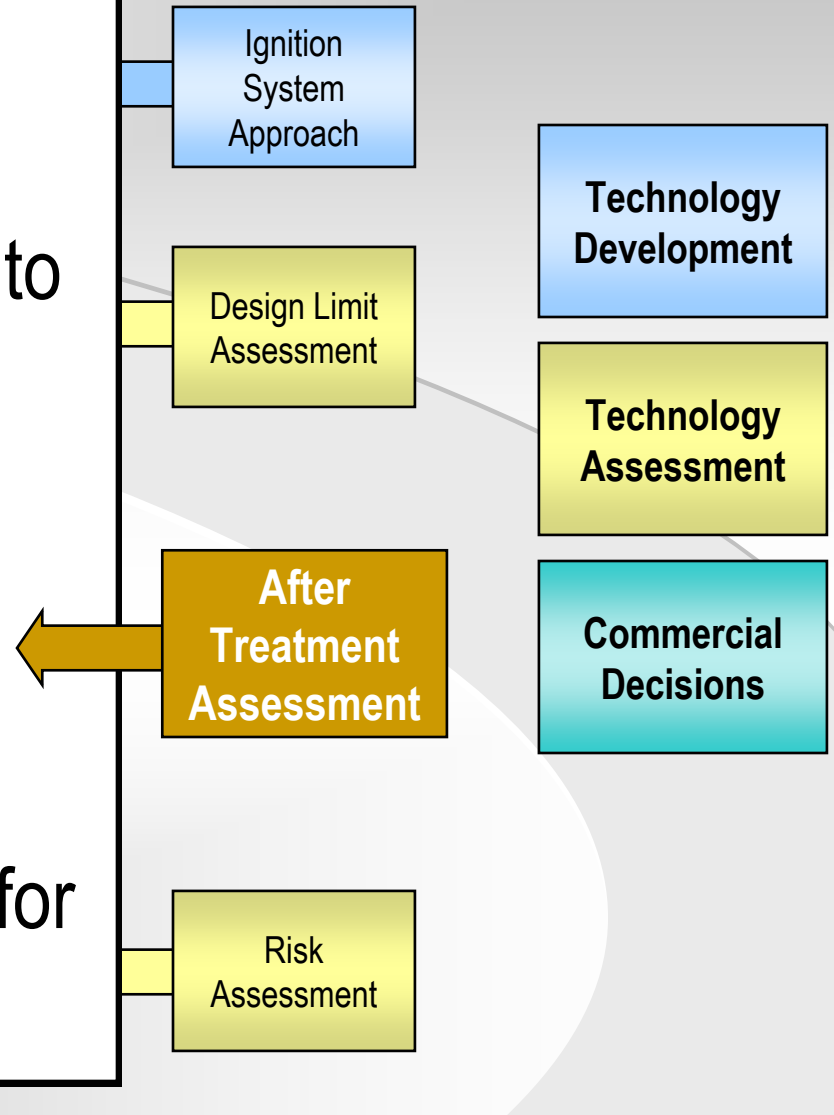
# APG Progress Update

## Approach

- Partner with after treatment supplier to integrate system into package to reduce cost

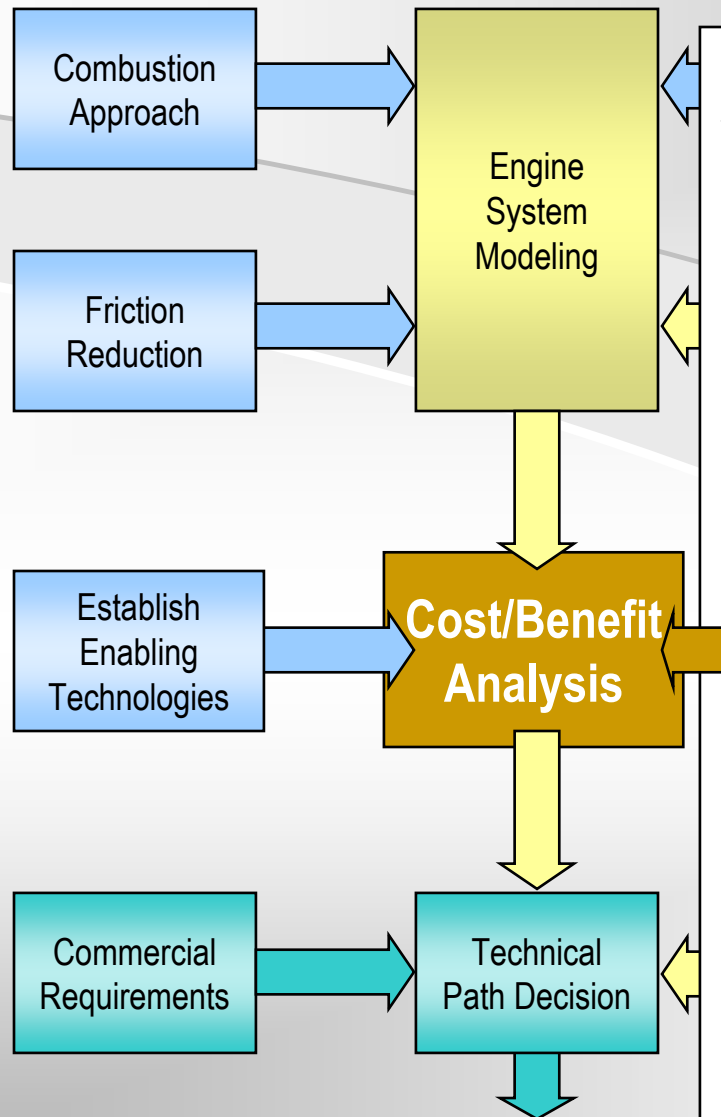
## Results

- Working with three potential after treatment suppliers and mutual interest established.
- <0.25 g/bhp-hr NOx potential for 2006





# APG Progress Update



## Approach

- Teardown analysis
- Value engineering

## Results

- 103 people generated over 400 separate ideas for review



# APG Project Milestones

## Task

1	Project Initiation	6/2001 ✓
1	Complete Program Management Plan	8/2001 ✓
1,2	Complete Subsystem Development	10/2002
1,2	Complete Control System Design	11/2002
4	Complete Lab Endurance Testing	9/2004
4	Complete Lab System Testing	10/2004
3	Complete Detailed Engine Design	1/2005
5	Begin Pre-Commercial Demo Test	4/2005
N/A	Production Engine Ready to Ship	6/2006



# Waukesha Release Path

- Phase I: Series 200, 40% BTE
- Phase II: APG, 45% BTE
- Phase III: Continued technology development, 50% BTE



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# APG Technology Accomplishments

- Improved stability: 50%
- Decreased burn duration: 15%
- Friction reduction: identified
- Increased spark plug life: 50%
- Engine & genset controllers: identified
- $<0.25$  g/bhp-hr NO<sub>x</sub> achievable for 2006
- Over 300 cost reduction ideas generated



# APG Summary

- APG project team, project plan and key partners in place
- Task 1 activities nearing completion
- Progress made on all major technical barriers
- APG is on track to meet the project goals

